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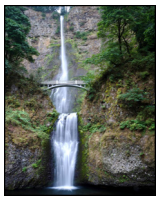

The potential role of actively open-minded thinking in preventing motivated reasoning about controversial science

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ABSTRACT

Ideologically motivated rejection of scientific evidence can be harmful to individuals and society, especially regarding consequential issues like climate change. A growing base of evidence suggests a cognitive style known as Actively Open-Minded Thinking (AOT) may reduce ideological rejection of scientific findings. In this article, we test the association between AOT and Americans' beliefs that global warming is mostly human-caused, a position supported by scientific consensus. We hypothesized that political conservatives with high AOT would be more likely than those with low AOT to acknowledge human-caused global warming. We predicted no such effect for liberals. Contrary to expectations, there was an unmoderated relationship between AOT and human causation belief. Higher levels of AOT were associated with increased likelihood of belief in human-caused global warming, regardless of participants' political ideology, scientific knowledge, or scientific media use. Implications for theory and practice are discussed.

1. Introduction

US Senator Daniel Patrick Moynihan, paraphrasing the words of others, famously said that “Everyone is entitled to his own opinion, but not to his own facts” (Doyle, Mieder, & Shapiro, 2012, p. 185). This quote expresses a wish held by many citizens and scientists alike: that even if disagreements over politics and values may be inevitable, all sides should be able to agree on matters of empirical fact.

Unfortunately, recent evidence has shown that ideological and political divides often drive disagreement on matters of scientific fact (e.g. Hornsey, Harris, Bain, & Fielding, 2016; Kahan et al., 2012). In the case of global warming, the rejection is thought to be ideologically motivated (Kahan et al., 2012). Conservatives generally value commerce and industry, and are skeptical of environmental regulations that would limit these valued activities (Kahan, Braman, Gastil, Slovic, & Mertz, 2007). Because conservatives see acceptance of global warming as likely to lead to additional regulations, they are motivated to reject evidence that suggests it is occurring (McCright & Dunlap, 2011). Liberals, on the other hand, are ideologically motivated to credit climate science, as it fits with their worldview with regards to the relative priorities of the environment versus industry (Kahan et al., 2007; McCright & Dunlap, 2011).

These kinds of ideological influences cause people to use motivated reasoning in their processing of scientific evidence. Motivated reasoning occurs when information is processed at the level of conscious awareness, but the nature of that processing is subconsciously skewed in a way that supports an individual's prior beliefs (Kunda, 1990; Lodge & Taber, 2013). In other words, rather than reviewing information with a goal of forming an accurate opinion, people subject incongruent evidence to more critical scrutiny (Lodge & Taber, 2013; Nyhan & Reifler, 2010; Redlawsk, 2002).

In this article, we examine one disposition – actively open-minded thinking (AOT) – that is a strong candidate for reducing motivated reasoning on controversial science. Our study offers two main contributions to the literature. First, we outline why we think AOT may be well qualified as an antidote to motivated reasoning. This explanation of AOT's theorized qualities has relevance beyond the study of AOT specifically, as it helps to illustrate general properties that effective dispositional safeguards against motivated reasoning will likely possess. This will help in identifying which other dispositions might succeed in reducing motivated reasoning. Second, our results provide evidence consistent with the argument that AOT does reduce motivated reasoning on climate change. Contrary to recent work (Kahan & Corbin, 2016), AOT should still be considered as a potentially important force

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to help solve one of the most important environmental problems of our time.

1.1. Actively open-minded thinking – why it may be well qualified to resist motivated reasoning

AOT has been described as "the tendency to evaluate arguments and evidence without undue bias from one's own prior beliefs" (Mellers et al., 2015). It is a thinking style, a dispositional tendency to think in a particular way, rather than a measure of cognitive ability like IQ. People high in AOT are thought to actively prevent their thinking from being weighted toward their initial beliefs by devoting increased effort to seeking out and actively considering contrary evidence (Baron, 1993; Haran, Ritov, & Mellers, 2013; Stanovich & West, 1997, p. 346). At the opposite end of the spectrum, those low in AOT display a thinking style primarily devoted to defending their prior beliefs. They do so by dismissing contrary evidence out of hand and spending less time and effort considering it. AOT is often described as a cognitive style (e.g. Baron, 2017; Haran et al., 2013; Mellers et al., 2015; Stanovich & West, 1997), and cognitive styles are thought to be generally stable characteristics (Kozhevnikov, Evans, & Kosslyn, 2014). However, to our knowledge, the stability of AOT over time has not been directly tested, and as we discuss further below, there is evidence suggesting that dispositions toward open-minded thinking can be changed via deliberate interventions (Abrami et al., 2015).

AOT is theorized to consist of two processes: increased seeking of counterattitudinal information, and higher levels of active processing of such information (Haran et al., 2013; Stanovich & West, 1997). As Baron (2008, p. 200) notes, "[AOT] is 'open-minded' because it allows consideration of new possibilities, new goals, and evidence against possibilities that already seem strong. It is 'active' because it does not just wait for these things but seeks them out". In this latter respect, AOT is similar to dispositions to central route processing that make cognitive elaboration more likely, such as need for cognition (NFC) (Petty & Cacioppo, 1986). However, AOT increases the elaboration likelihood for counterattitudinal evidence specifically, rather than causing increased tendency toward elaboration in general.

AOT has distinct properties from other similar measures of open-mindedness or critical thinking. Conceptually speaking, AOT is focused on actively reasoning against one's own beliefs – not just considering the possibility you are wrong, but also putting effort into thinking about why this might be so, and seriously considering changing one's current beliefs (Baron, 2017). If we consider motivated reasoning to be reasoning that is directionally biased by the subconscious wish to confirm one's prior beliefs, AOT would appear to be a subconscious bias in precisely the opposite direction – toward revising one's prior beliefs.

For this reason, AOT may be more effective in counteracting motivated reasoning than other measures of critical thinking, which tend not to focus on the direction of thinking (Baron, 2017, p. 3). For example, the Cognitive Reflection Test (CRT) measures the ability to suppress the initial response one has as a solution to a problem. While this does involve a kind of broadening of thinking, suppressing the first solution that comes to mind when solving a problem is not the same as actively overturning previously held beliefs. As Baron (2017, p. 4) notes, while people high in other forms of critical thinking might spend longer thinking carefully about some topic, "it is all too tempting to spend that extra time thinking of reasons why we are right and the other side is wrong. AOT as a trait counteracts this tendency."

Similarly, other measures of "open-mindedness" also do not involve this same focus on resistance to confirming one's own prior beliefs. For example, the "Big Five" openness to experience scale measures a disposition to engage in unconventional or original thinking (Gosling, Rentfrow, & Swann, 2003). While this disposition does involve resistance to thinking like other people typically would, this is different to a disposition toward revising what *you yourself* previously believed. To summarize, assuming it operates as theorized, AOT may reduce motivated reasoning, due to its directional nature – actively and fairly considering evidence *against* one's prior beliefs. Any disposition that has these features should provide resistance to motivated reasoning.

Of course, it is not enough to say that AOT "should" offer resistance to motivated reasoning, simply because of how it is conceptually thought to operate (Kahan & Corbin, 2017). In addition, we need two forms of empirical evidence, demonstrating both that AOT is operationally distinct from other similar concepts, and that AOT actually does lead to resistance to motivated reasoning. Past studies support the idea that high AOT is associated with more extensive seeking of information (e.g. Haran et al., 2013) and information processing that is less biased by prior beliefs (e.g. Stanovich & West, 1997), making it plausible that AOT would reduce motivated reasoning as well. Part of the goal of the present study is to provide additional evidence to help test whether AOT reduces motivated reasoning about climate change.

In terms of discriminant validity, several studies have provided strong evidence that AOT is distinct from other measures such as NFC, need for closure, cognitive reflection, openness to experience, and religiosity. For brevity's sake, we have put discussion of this evidence in this article's supplementary material. In sum, based on this evidence, as well as the conceptual nature of AOT, we argue there is good reason to believe AOT may be effective in overcoming motivated reasoning.

1.2. Previous research on AOT and beliefs about science

In 2016, Kahan and Corbin published a study looking at how AOT relates to belief that climate change is human-caused. They conducted a cross-sectional survey, using a YouGov sample of 1600 US adults. They measured AOT with a slightly altered version of the 7-item AOT scale first used by Haran et al. (2013), and measured climate beliefs with two questions. The first asked whether there is "solid evidence that the average temperature on earth has been getting warmer over the past few decades". If participants responded "Yes", the second question asked whether the warming trend was "mostly because of human activity such as burning fossil fuels".

A large part of Kahan and Corbin's (2016) paper relates to the broader debate over whether polarization on climate change is due to asymmetry in the distribution of open-mindedness across conservatives and liberals. However, most important for the present discussion was their finding that AOT was associated with increased polarization on climate change. Higher AOT was associated with higher likelihood of belief in human causation for liberals, and lower likelihood of belief for conservatives. They interpret this result as signifying that for the issue of climate change, AOT "enhances the proficiency of reasoning aimed at forming identity-congruent beliefs" (Kahan & Corbin, 2016, p. 3). In other words, AOT acts in the same way that scientific knowledge did in the Kahan et al. (2012) and Bolsen, Druckman, and Cook (2015) studies, and makes individuals better able to selectively support their group's preferred position.

If their interpretation is correct, it would suggest that contrary to the hope that AOT reduces motivated reasoning, it in fact can amplify it. However, there were significant problems with their analysis.[1] Specifically, we focus on the lack of a measure of scientific knowledge, or the interaction of scientific knowledge with political ideology, in their regression model. This is a problem because Kahan's own research (Kahan et al., 2012) has suggested that the interaction between scientific knowledge and ideology is an important influence on views on climate change, with higher scientific knowledge being associated with greater perceived risk for liberals, but lower perceived risk for conservatives. We cannot be sure that the observed relationship between AOT and climate beliefs is not distorted by the failure to control for other important factors. Drawing stronger conclusions about AOT's effects requires an analysis that controls for the interaction of scientific knowledge and political ideology, something our study offers. In addition to this strengthened analysis, we also build upon previous research with our explication of the process by which AOT might

encourage alignment of views with scientific consensus among people of divergent political ideologies. As we show, this explication helps identify potentially important moderators of AOT's effects, which we also set out to test.

1.3. How AOT could encourage consensus-consistent beliefs

For individuals whose ideological biases push them to reject consensus science, high levels of AOT should make them more likely to overcome these biases and accept the consensus position. However, the mechanism for this belief change is not what might be expected based on certain understandings of the phrase "open-mindedness". If AOT merely made people prone to credit the validity of *any* evidence they encounter, regardless of the strength of that evidence, it would be as likely to have negative as positive effects. For example, under this conceptualization, high-AOT individuals who believed in global warming would be highly receptive to messages from climate skeptics, and if they encountered such messages, would likely convert to skepticism themselves.

A closer reading of theoretical conceptualizations of AOT suggests that it is not thought to operate in this fashion. AOT does not cause individuals to change their beliefs directly, in response to any new information they hear. As Baron (2008, p213) states, people high in AOT show high support for "revising their beliefs *if it is warranted"* (emphasis added). AOT *does* make people more likely to devote effort to analyzing information that goes against what they already believe (Baron, 2008; Haran et al., 2013). However, merely considering this evidence does not guarantee that the individual's attitude will change. Whether their attitude changes will be determined by the individual's subsequent appraisal of the strength of the evidence. AOT thus operates in a fashion similar to accuracy goals as described by Kunda (1990) and Fiske and Taylor (1991). Because the motivational goal is to form accurate beliefs, as opposed to either changing beliefs or keeping them the same, beliefs should only change when belief change seems likely to make one's belief more accurate. As Baron (2008, p200) argues, one of the principles of AOT is "*fairness* to other possibilities than the one we initially favor" (emphasis added), rather than *acceptance* of other possibilities. If AOT motivates an individual to consider counterattitudinal evidence, but they do not appraise that evidence to be strong, then high AOT should not lead to belief revision.

These theoretical assertions are supported by empirical findings. In one study (Stanovich & West, 1997), participants were presented with 23 short arguments and asked to judge their strength. Of the 23 arguments, 14 were rated as weak, on average, by a panel of eight expert judges (six philosophy professors and the study authors themselves). Participants high in AOT were more likely than those low in AOT to rate arguments as weak that the judges had also rated as weak. Additionally, judgments of argument strength by participants high in AOT were less influenced by participants' own prior views on the topics. This suggests that AOT enables individuals to consider counterattitudinal information, but does not make them uncritical consumers of such information.

If this conceptualization of AOT is correct, it implies that AOT should have different effects on global warming beliefs for liberals and conservatives. This point is critical in understanding what we should expect to see in our results. Since conservatives and liberals have different beliefs, when AOT causes them to seek out information that goes against those beliefs, they will seek out different kinds of information, with different results.

To explain in more detail, conservatives low in AOT will be motivated to reject any information suggesting that global warming is human-caused; conservatives high in AOT will be more likely to seek out and attend to this information. Because the evidence for human-caused global warming is strong (IPCC, 2014), attending closely to the information will make them more likely to accept this evidence and believe in line with the scientific consensus. Therefore, for conservatives, AOT should be positively associated with belief in human-caused global warming.

For liberals, on the other hand, AOT should have no relationship to their belief in human-caused global warming. For liberals, counter-attitudinal messages are those that suggest global warming is *not* occurring. Again, if the conceptualization above is correct, AOT should make liberals more likely to seek out and seriously consider this kind of counterattitudinal message. However, because the evidence for this argument is weak (IPCC, 2014), attending to this kind of message and appraising its quality should not make liberals more likely to doubt global warming. Liberals low in AOT who never consider counter-attitudinal evidence will follow their predisposition to believe in human-caused global warming; liberals high in AOT who consider counterattitudinal evidence will end up with the same belief – that global warming is real – that they originally had. Thus, our prediction for AOT's effects is different from Kahan and Corbin (2016). While we argue that AOT should increase belief in climate change for conservatives, and have no effect for liberals, they argue that AOT decreases belief for conservatives, and increases belief for liberals. They argue this occurs because AOT "enhances the proficiency of reasoning aimed at forming identity-congruent beliefs" (2016, p3).

Contrary to their argument, we posit:

H1: There will be an interaction between AOT and political ideology, such that AOT is positively associated with belief in human causation for conservatives, but not for liberals.

While AOT should affect climate beliefs for at least some people, additional conditions may need to be met for these effects to emerge. First, the effect of AOT on belief revision may be contingent on adequate exposure to high-quality scientific evidence. If a person is never exposed to high-quality information on the scientific evidence for global warming, it might make little difference how open-minded they are; they may not have the opportunity to form an accurate belief about the evidence, because they will not have heard what that evidence is. If a person is regularly exposed to high-quality scientific evidence, however, in addition to being high in AOT, this would give them the opportunity to revise their beliefs to be accurate. Therefore, individuals with high exposure to scientific media sources may be more likely to demonstrate an effect of AOT.

Second, information should only change an individual's beliefs if the information *as appraised by that individual* is sufficiently persuasive. Suppose a high-AOT individual considers some high-quality scientific information that, objectively speaking, "should" change their beliefs to the position of expert consensus. If that individual lacks the scientific comprehension to properly appraise the weight of that evidence, they will have little reason to weight the scientific evidence highly in making their decision of what to believe. However, if they do have a high level of scientific knowledge, they will be more likely to appraise the evidence accurately, and appropriately revise their beliefs. Therefore, in our research we investigate the possible roles of both science media use and scientific knowledge:

RQ1: Will the AOT-ideology interaction only emerge at a high level of (a) science media use, (b) scientific knowledge, or (c) both?

2. Method

We tested our hypothesis and research question using a quota sample of 1000 US adults, provided by the survey firm YouGov. For more details on our rationale for choice of sample size, sample representativeness, or other aspects of the sampling process, see the supplementary material. Fourteen participants who completed the survey did not answer the question about global warming causation beliefs that we used as our dependent variable. These participants were removed from the analysis, leaving us with a total N of 986 for all analyses reported below.

The survey questions used for our study were part of a larger survey on how the US public perceives scientists, as well as other related topics. Participants completed the survey in their web browser. Median time to complete the survey was 20 min and 7 s. For a full list of measures included in the survey, see the supplementary material.

Since there was relatively little missing data among the independent variables (percentage missing range: 0% to 2.5%; *M*: 0.78%), we used hotdeck imputation (Myers, 2011) to replace missing values for independent variables – a more effective process than listwise deletion (Hawthorne & Elliott, 2005; Roth, Switzer, & Switzer, 1999). Hotdeck imputation is an automated procedure that in this case sorted the participants by gender and education level and replaced any missing values with values from randomly selected participants who were similar in terms of gender and education.

2.1. Measures

A table of bivariate Pearson's *r* correlations between variables can be found in the Supplementary Material (Table S10).

2.1.1. Demographics

Age was a continuous variable measured in years ($M = 49.0$, $SD = 17.0$). Gender was dichotomous, coded either as 1 (*male*, 46%) or 2 (*female, 54%*). Race was also dichotomous, and was based on two questions: One asking whether participants were Hispanic or Latino, and another question asking them to check all racial categories that applied to them. Participants who selected any categories other than *Not Hispanic or Latino* and *White* (27%) were coded as 1; all other participants (73%) were coded as 0. Finally, education was entered as an ordered categorical variable with six categories: 1 (*Did not graduate from high school*), 2 (*High school graduate*), 3 (*Some college, but no degree (yet)*), 4 (*2-year college degree*), 5 (*4-year college degree*), and 6 (*Postgraduate degree*). The median level of education was *Some college*.

2.1.2. Political ideology

Political ideology was measured with a single question: "In general, do you think of yourself as politically …" Answer categories were 1 (*Very Liberal*), 2 (*Somewhat Liberal),* 3 (*Moderate, middle of the road*), 4 (*Somewhat Conservative*), and 5 (*Very Conservative*). This variable ($M = 3.08$, $SD = 1.25$) was standardized prior to being used in analysis.

2.1.3. Actively open-minded thinking (AOT)

AOT was measured with the 7-item scale used by Haran et al. (2013) and Mellers et al. (2015). This included items such as "Allowing oneself to be convinced by an opposing argument is a sign of good character" and "Intuition is the best guide in making decisions" (reverse coded). Responses were given on a seven-point scale, ranging from 1 (*Completely Disagree*) to 7 (*Completely Agree*), with 4 (*Neutral*) at the midpoint. Other points on the scale were not labeled. Item wordings for the full scale are available in the supplementary material. Before analysis, all items were averaged to form a single AOT score ($M = 4.9$, $SD = 0.91$), which was then standardized. Cronbach's alpha for the scale, after recoding reverse-coded items, was 0.67. Although this is somewhat lower than what is normally considered acceptable reliability, it is comparable to previous studies that reported reliability of the scale, such as Kahan and Corbin (2016) and Svedholm-Häkkinen and Lindeman (2018), both of which reported an alpha of .61, and Mellers et al. (2015), which reported an alpha of .65.

2.1.4. Scientific knowledge

Seven items, previously used by Miller (1998) and the National Science Board (2014), which are largely similar to those used by Kahan et al. (2012), were used to measure scientific knowledge. Six of the items were true/false questions, such as "The center of the Earth is very hot" and "All radioactivity is man-made". The other question asked "Does the Earth go around the Sun, or does the Sun go around the Earth?", for which answer options were "Earth goes around Sun" and "Sun goes around Earth". Item wordings for the full scale are available in the supplementary material. Before analysis, the number of correct items were summed ($M = 5.6$, $SD = 1.3$) and then standardized to form a single index of scientific knowledge. The seven dichotomous variables, representing whether participants got each question right or not, together had a Kuder-Richardson KR20 statistic (a version of Cronbach's alpha for dichotomous items; Cortina, 1993) of 0.48. Although this is lower than conventional standards for Cronbach's alpha, reliability of scales of true/false scientific literacy questions have been found to be close to this level across many countries (Pardo & Calvo, 2004). Combined with the fact that relatively few items were used compared to previous studies (e.g. Kahan et al., 2012), we considered this level of reliability acceptable for the present context.

2.1.5. Scientific media use

Scientific media use was measured with five items. Two items asked participants "How closely do you follow news about each of the following topics?" followed by the topics "Science and technology" ($M = 2.3$, $SD = 0.91$) and "The environment" ($M = 2.3$, $SD = 0.93$). Answer options for these two items were on a four-point ordinal scale: 1 (*Not at all closely*), 2 (*Somewhat closely*), 3 (*Closely*), and 4 (*Very closely*). Another three items began with the question stem "How often would you say you do each of the following?" followed by the options "Watch television programs or channels about science, such as Cosmos or Discovery Channel" ($M = 3.0$, $SD = 1.1$) "Visit science websites and blogs, such as NOAA.gov or Sciencedaily.com" ($M = 2.3$, $SD = 1.1$) and "Read science magazines, such as Popular Science or Scientific American" ($M = 1.9$, $SD = 1.0$). Response options were on a five-point ordinal scale: 1 (*Never*), 2 (*Rarely*), 3 (*Sometimes*), 4 (*Often*), and 5 (*All of the time*). Before analysis, scores on each item were standardized, and then all items were averaged together to form a single index, which was standardized again. Cronbach's alpha for the scale of standardized items was 0.79.

2.1.6. Dependent variable – belief in anthropogenic global warming

Belief that global warming is human-caused was measured by participants' response to the statement "Humans have caused most of the global warming that has taken place over the last 50 years." Response options were "True" (selected by 55% of participants), "False" (25%), and "The evidence is currently inconclusive" (20%). These responses were recoded to a dichotomous variable with values of 1 (*True*) or 0 (*False* or *The evidence is currently inconclusive*). The variable was coded in this way so as to clearly distinguish between all those individuals who agreed with the scientific consensus position, and those who did not (IPCC, 2014). Although this variable obscures much important variation in the views of those who dissent from the consensus position, for our purposes, we were most interested in measuring which predictor variables were associated with having correct (i.e. consensus-consistent) as opposed to incorrect beliefs. We were not interested in examining what distinguished those with incrementally less wrong beliefs (i.e. those who said "Inconclusive") from those with incrementally more wrong beliefs (those who said "False").

2.2. Methodological notes

We used a set of logistic regression models to test our hypothesis and address our research question. Interaction terms were created by multiplying standardized variables together. In order to test H1–the prediction that AOT would have a positive relationship to belief in human causation for conservatives, but not for liberals – it was necessary to run models including at least a two-way interaction term. If the two-way ideology-AOT interaction turned out to be significant, this would provide evidence to support H1. However, we were not sure whether the emergence of this interaction would depend on scientific knowledge and science media use. Therefore, we also tested models

Table 1
Logistic regression models predicting belief in human-caused global warming.

	Model 1	Model 2	Model 3	Model 4
Political ideology	**−1.19*****	**−1.19*****	**−1.18*****	**−1.16*****
AOT	**.21***	**.23***	**.22***	**.24***
Knowledge	**-.23****	**-.23****	**-.28****	**-.33****
Media use	**.24****	**.23****	**.26****	**.27****
Two-way interactions				
Ideology x AOT		-.13	-.16	-.14
Ideology x Knowledg	**-.41*****	**-.37*****	**-.37*****	**-.43*****
Ideology x Media use			-.19	-.21
AOT x Knowledge			-.13	-.14
AOT x Media use			.11	.13
Knowledge x Media use				-.13
Three-way interactions				
Ideology x AOT x Knowledge			-.06	-.11
Ideology x AOT x Media use			-.19	-.21
Ideology x Knowledge x Media use				-.12
AOT x Knowledge x Media use				-.05
Four-way interaction				
Ideology x AOT x Knowledge x Media use				-.10
Demographics				
Age	**-.01***	**-.01***	**-.01***	**-.01***
Gender	.20	.21	.18	.19
Race	.20	.21	.21	.21
Education	-.06	-.07	-.06	-.06
Nagelkerke R^2	.37	.37	.38	.38
N	986	986	986	986

Notes: *p < .05, **p < .01, ***p < .001. All cell entries, apart from the bottom two rows of the table, are unstandardized logistic regression coefficients.

including three-way and four-way interaction terms involving political ideology, AOT, scientific knowledge, and science media use. In each of these models with higher-order interactions, all necessary lower-order interactions were included as well (as can be seen in Table 1).

If a higher-level interaction term turned out to be significant, and involved a positive relationship between AOT and human causation belief for conservatives but not liberals, this would also support H1. In addition, these analyses of higher-level interactions would answer our research question about whether the emergence of the ideology-AOT interaction depended on the other variables. To obtain tests of the relevant three-way and four-way interactions, several lower-order interaction terms had to be included (in Models 3 and 4); we excluded all lower-order interactions that were not necessary component parts of the higher-order interactions of interest.

All these analyses are presented as Models 1–4 in Table 1, and are discussed further below. Model 1 includes only one interaction between ideology and scientific knowledge, and no other interactions. We added this model in order to test for a non-moderated relationship between AOT and belief in human causation, after none of the interactions involving AOT turned out to be significant. Below, we discuss Models 2–4 first, prior to Model 1, because Models 2–4 directly address H1 and RQ1.[2]

We planned to test models including all these variables, including all the interaction terms, prior to receiving data. However, we did not decide on the exact mathematical form or number of models, or preregister which models we planned to present, prior to receiving data. These additional "researcher degrees of freedom" (Simmons, Nelson, & Simonsohn, 2011) mean that none of our models can be considered to be fully confirmatory.

Model 2 in Table 1 represents the simplest test of H1. In Model 2, in addition to the ideology-AOT interaction, one other two-way interaction term was included: the ideology-scientific knowledge interaction. Since Kahan et al. (2012) and Bolsen et al. (2015) had found this interaction to be significant, we wanted to control for its effects while testing the ideology-AOT interaction. The relationship between media use and the dependent variable was also included in Model 2 to control for the potential influence of scientific media use on global warming beliefs.

3. Results

All the models tested failed to provide any support for H1. The ideology-AOT interaction we predicted failed to emerge. Additionally,

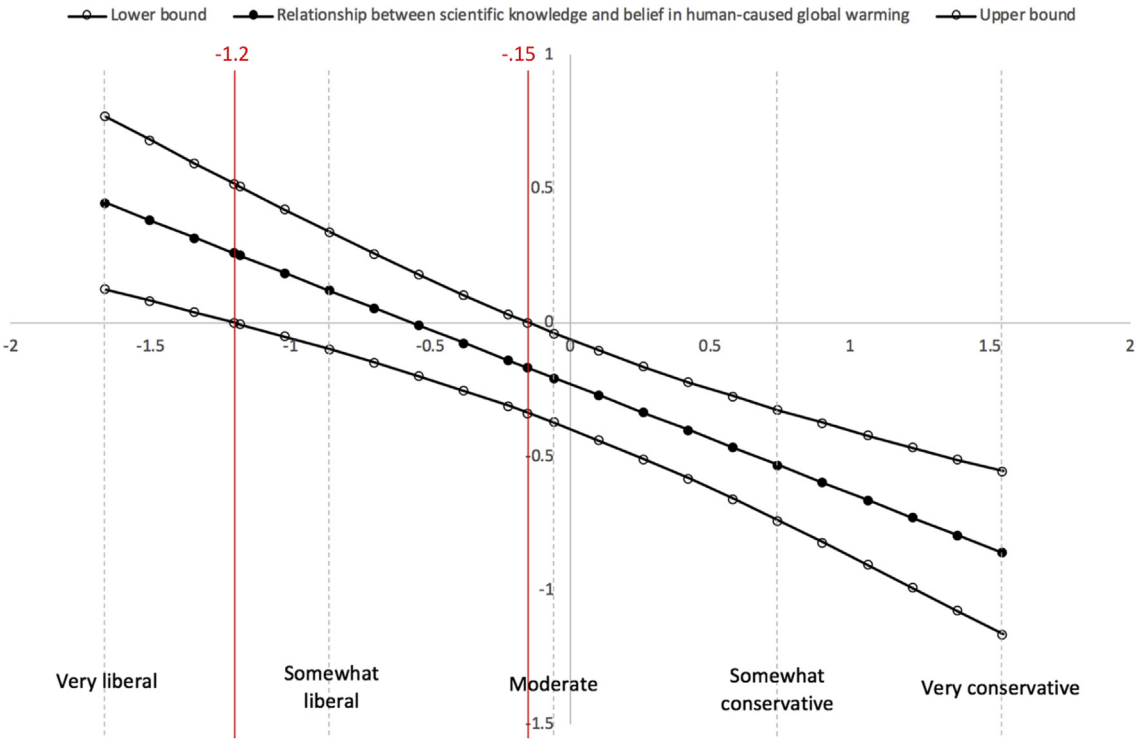

Fig. 1. Interaction between political ideology and scientific knowledge.

Models 2, 3 and 4 together give us an answer to RQ1, which asked whether or not the ideology-AOT interaction would depend on levels of scientific knowledge and/or media use. This question is clearly answered in the negative; the predicted interaction did not emerge at all.[3]

Although our theoretical prediction focused on AOT's interactions with other variables, the interactions involving AOT were not significant. Therefore, we also ran a model – Model 1 in Table 1 – testing for an unmoderated relationship between AOT and human causation beliefs. This unmoderated relationship was positive and significant. In this model, higher levels of AOT were associated with greater likelihood of believing global warming is human-caused, for all participants.

The size of this relationship, in substantive terms, is easiest to understand in terms of differences in probability of belief in human causation. As the outcome was measured with logistic regression, probability differences are not uniform across all levels of the outcome (rather they are uniform in the log odds). Therefore, when looking at how the probability varies as a function of an independent variable, it is necessary to specify the level of the dependent variable at which we are starting. Therefore, we chose a participant with an overall predicted likelihood of 55% of believing in human-caused global warming. We thought this was a relevant example since the overall proportion of people believing in human causation was about 55%. All else being equal, compared to this kind of person, someone one standard deviation higher in AOT would have a predicted probability of belief in human causation of about 60%, a difference of about 5%.

While investigating AOT was our main purpose, results not involving AOT were also of interest. In Models 1 and 2, we replicated the interaction found by Kahan et al. (2012) and Bolsen et al. (2015) between ideology and scientific knowledge.[4] A plot of this interaction is displayed in Fig. 1.

Fig. 1 is based on a floodlight analysis for Model 1. The y axis represents the relationship between scientific knowledge and belief in human-caused global warming, expressed as an unstandardized logistic regression coefficient. The x axis represents political ideology. As this variable was standardized for analysis, the units of this axis are standard deviations, with zero representing the mean. The points representing the five scale points respondents actually used (very liberal, somewhat liberal and so on) are represented by the dashed vertical lines, with labels at the bottom of the figure.

Floodlight analyses test the simple relationships between an independent variable and the dependent variable across all values of a moderator variable (Spiller, Fitzsimons, Lynch, & McClelland, 2013). In the present case, this shows the exact values of political ideology for which the relationship between scientific knowledge and belief in human-caused climate change is statistically significant. There is one area of significance to the left of the solid vertical line at −1.2 on the x-axis (between "Very liberal" and "Somewhat liberal"). For all individuals on the liberal side of that line, scientific knowledge has a significant positive relationship to belief in human causation. There is another area of significance to the right of the solid line at −0.15 on the x-axis (between "Somewhat liberal" and "Moderate"). For all individuals on the conservative side of that line, scientific knowledge has a significant negative relationship to belief in human causation. Between the two lines, the relationship between knowledge and belief in human causation is not significant. Fig. 2 displays the same interaction, graphed to show predicted probability of belief in human-caused global warming on the Y-axis, instead of the relationship between scientific knowledge and belief in human-caused global warming.

Another finding of interest, although tangential to the central purpose of the study, was the bivariate correlation between political ideology and AOT: $r = -0.30, p < .001$. Higher levels of conservatism were associated with lower levels of AOT. In terms of group averages, "Somewhat liberal" and "Very liberal" participants together had an average AOT score of 5.3 on the 7-point scale ($SD = 0.91$). "Somewhat conservative" and "Very conservative" participants together had an average score of 4.6 ($SD = 0.87$). Finally, the supplementary material addresses the possibility that AOT could mediate the relationship between political ideology and belief in human caused global warming.

4. Discussion

Our hypothesis, that AOT would interact with political ideology, was not supported. Furthermore, the answer to our research question – about whether the ideology-AOT interaction would be dependent on other variables – was also negative. AOT had a positive relationship to belief in human causation, regardless of other explored participant characteristics. For people across the spectrum of political ideology, having an actively open-minded thinking style was associated with being more likely to agree with the scientific consensus on global warming.

The size of the relationship between AOT and human causation belief was not very large, but was still substantively meaningful. As discussed above, for an individual who would otherwise have a 55% chance of believing global warming is human-caused, a one standard deviation difference in AOT would be associated with about a 5% difference in likelihood of belief. For comparison, this is just over one third

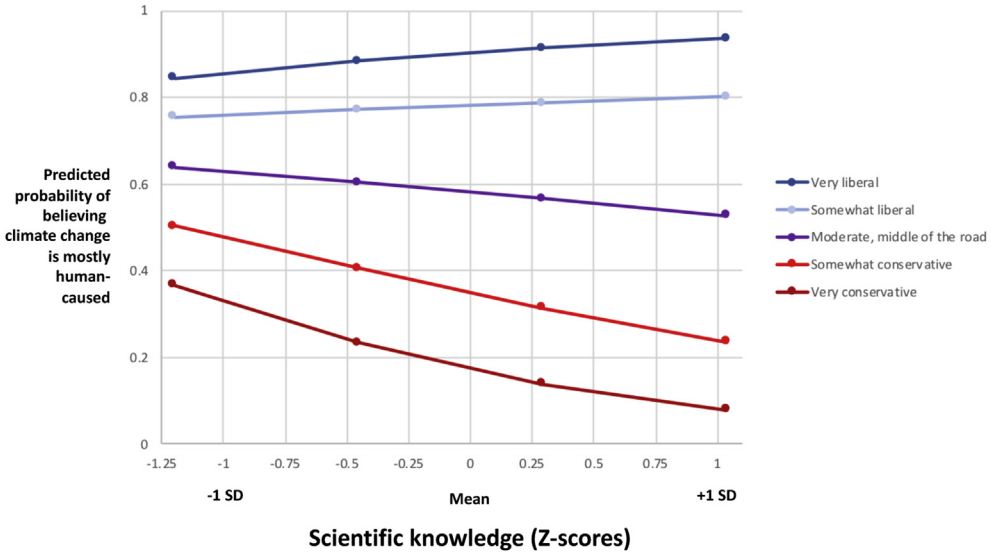

Fig. 2. Interaction between political ideology and scientific knowledge.

of the difference found between Independents and Republicans' likelihood of believing global warming is mostly human-caused in a recent survey (Leiserowitz et al., 2017). For an issue that is so important, yet so polarized and difficult to shift beliefs about, even this amount of change could be meaningful.

Our results provide a very different picture of AOT's relationship to climate beliefs than the polarizing relationship found by Kahan and Corbin (2016). However, we still cannot be sure exactly *why* AOT is related to beliefs about the human causation of climate change. Our empirical results are consistent with several potential explanations that would have very different implications for our understanding of how AOT affects beliefs about science. The positive relationship between AOT and climate beliefs for liberals is problematic for our understanding of how AOT works. If our theoretical predictions were accurate, and high-AOT liberals attended to more arguments skeptical of global warming than low-AOT liberals, why would this make them *more* likely to believe in human-caused global warming?

One possible explanation is that we were wrong when we assumed that all liberals are predisposed to believe in global warming. Despite liberals generally being more accepting of global warming than conservatives, a substantial minority of liberals may still find the idea of human-caused global warming unpleasant, and prefer to reject it. The positive relationship between AOT and belief for liberals may be due to this subset of liberals, for whom motivated reasoning would normally push them to reject evidence for human causation, being more likely to attend to this evidence, and come to believe in human causation as a result. Thus, both sides of the spectrum – liberals and conservatives alike - contain a certain portion of individuals who are motivated not to believe in global warming, and who do not believe in it if low in AOT, but *do* believe in it if high in AOT.

Another explanation could be that attending more strongly to climate skeptic arguments resulted in a boomerang effect for liberals. It might be the case that most liberals resist attending to climate skeptic arguments in detail, but nevertheless assume that these arguments are not of extremely poor quality. However, if high-AOT liberals attended to these arguments in detail, they might be surprised by their low quality, and respond by becoming more stridently in favor of human causation than they were before. Examples of this kind of boomerang effect, caused by centrally processing an argument one finds to be weak, have been found previously (e.g. Miller, 1965; Paletz, Koon, Whitehead, & Hagens, 1972; Park, Levine, Westerman, Orfgen, & Foregger, 2007; Petty & Cacioppo, 1986).

Importantly, in both of these cases, AOT is still reducing motivated reasoning and making people more likely to align their views with the best available scientific evidence. The primary contribution of our study is to show that AOT, which seems a good candidate for reducing motivated reasoning based on its conceptual nature, remains a good candidate when taking the empirical record into account. Although more research needs to be done, at the very least AOT seems too relevant a concept to be ruled out prematurely.

While more evidence is needed to better understand AOT's effects, we can be confident that the present results are not consistent with the account of Kahan and Corbin (2016). They argued that AOT *amplifies* motivated reasoning. However, if conservatives high in AOT were more likely to selectively reinforce their view that global warming is not human-caused, then we should expect high-AOT conservatives to be less likely to believe in global warming - the opposite relationship to the one we have observed in our study. The two explanations in the paragraphs above are consistent with our data; Kahan and Corbin's (2016) account is not.

If AOT does cause people to be more likely to form accurate beliefs about global warming (which our correlational research cannot determine), this would have important implications for both theory and practice. Theoretically speaking, it would suggest that an actively open-minded thinking style may achieve what scientific knowledge alone cannot (Bolsen et al., 2015; Kahan et al., 2012), namely, the reduction of ideologically motivated reasoning on controversial science. Therefore, additional research on the role of cognitive dispositions such as AOT would appear to be warranted.

Practically speaking, if AOT reduces motivated reasoning, then interventions designed to increase AOT might be effective in encouraging individuals of diverse ideological backgrounds to be more open to scientific evidence they would otherwise reject. To our knowledge, interventions designed to boost AOT have not been conducted. However, there is substantial evidence suggesting that other dispositions toward critical thinking can be deliberately increased. For example, a recent meta-analysis (Abrami et al., 2015) has shown that interventions designed to increase critical thinking dispositions have positive effects. Future studies should test whether AOT is a teachable skill, and whether increases in AOT lead to reduced resistance to counterattitudinal information.

As explained above, it is possible that AOT may reduce motivated reasoning. However, our findings could also be explained by other mechanisms. For example, it may be the case that AOT is serving as a proxy for some other unmeasured variable, such as deference to scientific authority (Brossard & Nisbet, 2007). In this case, the relationship between AOT and human causation belief may be spurious, and due to AOT being positively correlated with deference. If this were true, increasing individuals' AOT would have no beneficial effect on their beliefs about controversial science.

This kind of explanation is worth considering for two reasons. First, we did not directly measure how much individuals had read about global warming. Without directly measuring the extent to which high-AOT individuals seek out and process counterattitudinal information on issues like global warming, our argument that this is what happens is weakened.

Second, the relationship between AOT and human causation belief was the same for individuals with different levels of science media use. If the effect of AOT is the same for those with very low and very high levels of science media use, then it seems less plausible to believe that it operates entirely through detailed processing of scientific evidence. Without confirming the mechanism of AOT via direct measurement of counterattitudinal reading habits, we should remain cautious about this explanation.

Another noteworthy result was our replication of Kahan and Corbin's (2016) finding that conservatives are generally lower in AOT than liberals. This echoes the findings of other scholars who have examined psychological asymmetry between conservatives and liberals (e.g. Bullock, 2011; Jost & Krochik, 2014; Jost, 2017) and is contrary to other recent findings of psychological symmetry between the two groups (e.g. Kahan et al., 2012; Nisbet, Cooper, & Garrett, 2015). Thus, even if AOT has the same positive effect on beliefs for both liberals and conservatives, the relative proportion of conservatives who currently benefit from high levels of AOT appears to be smaller.

Along similar lines, one further limitation of the present study was that we only examined one issue – global warming – in which conservatives are predisposed to reject the scientific consensus position, but liberals are not. To better understand the effects of AOT on perceptions of controversial science more generally, future research should examine other issues, such as the safety of nuclear power, where conservatives are more likely than liberals to be aligned with the views of mainstream scientists (Kahan et al., 2012). Measuring key variables such as climate change causation beliefs and political ideology with multiple-item scales would also increase the precision of results, as would the use of measurement scales with higher reliability.

Notes

1. Baron (2017) has also raised objections to Kahan and Corbin's (2016) interpretation of their results. We encourage readers to read his article, as well as the subsequent reply by Kahan and Corbin (2017). We do not address Baron (2017) or Kahan and Corbin

(2017) in greater detail because neither of these papers include an analysis that controls for the interaction of scientific knowledge and ideology. Since this influence is not controlled for, we cannot be confident that any of the empirical results discussed provide a clear picture of AOT's true effects.

2. We felt it would be easier to read Table 1 if it followed the conventional format whereby the simplest model is displayed in the leftmost column, and models become more complex moving from left to right. Therefore, we placed the simplest model to the left of the table, and labeled it Model 1.
3. Although the three-way and four-way interactions were not significant in Models 3 and 4, several two-way interaction terms were significant in those models. However, since these were conditioned on the presence of non-significant higher-level interactions, we do not interpret them here, as it is inappropriate to probe the lower-level components (in this case, the two-way interactions), when the higher order interaction is not significant.
4. In order to more directly replicate the findings of Kahan et al. (2012) and Bolsen et al. (2015), we also tested whether the interaction between ideology and scientific knowledge remained significant when AOT and scientific media use were not included in the model. The interaction indeed remained significant. Results can be seen in Supplementary Material Table S9.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvp.2018.06.001.

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